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VEGETATION BIOMASS PREDICTION IN THE CATTLE CORRIDOR OF UGANDA

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ABSTRACT

Pastoralists in Sub-Saharan Africa face complex problems notably frequent and severe droughts. This study was conducted in the cattle corridor of Uganda, a largely semiarid area to estimate the likely vegetative biomass production under the 2071-2100 projected rainfall conditions. Spatio-temporal pattern of vegetative biomass production were determined by analysis of the seasonal variation of Normalised Difference Vegetation Index (NDVI) for 10 years from 2001-2010. A biomass relationship was established between the NDVI and the Standardised Precipitation Index (SPI); and used to project the period 2071-2100 NDVI using downscaled rainfall for the cattle corridor. A change trajectory performed on the annual means revealed the highest increase in vegetation in 2008 (0.031) and decrease in 2009 (-0.022). The SPI revealed two main droughts that were established to have occurred in the years of 2004 - 2005 and 2008-2009. The wettest year was 2003 and corresponded with the increase in NDVI. A strong positive correlation of rainfall and vegetation was established (r=0.99). Precipitation has influenced vegetative biomass in the cattle corridor as there is a positive correlation between precipitation and the vegetative biomass production. Secondly, vegetation is likely to be concentrated in areas that will have high precipitation in 2070-2100, such as Luwero and the districts south of it of the cattle corridor compared to those in the north of the cattle corridor of Uganda.

Key Words: NDVI, precipitation, rainfall, SPI

RÉSUMÉ

Les éleveurs en Afrique Sub-saharienne se confrontent aux problèmes complexes notamment les sécheresses fréquentes et plus graves. Cette étude a été menée dans le corridor du bétail de l'Ouganda, une région largement semi-aride pour estimer la production susceptible de biomasse végétale sous les conditions pluviométriques projetées en 2071-2100. Le modèle spatio-temporel de production de biomasse végétale a été déterminé par l'analyse de la variation saisonnière de l'Indice de Végétation par Différence Normalisée (NDVI) pendant 10 ans dans l'intervalle de temps 2001-2010. Une relation de biomasse a été établie entre l'indice de végétation NDVI et l'indice de précipitations normalisé (SPI), et elle est utilisée pour projeter le NDVI de la période 2071-2100 en utilisant les précipitations à échelle réduite pour le corridor du bétail. Une trajectoire de changement effectuée sur les moyennes annuelles a révélé la plus forte augmentation de la végétation en 2008 (0,031) et une diminution en 2009 (-0,022). Le SPI a révélé deux principales sécheresses qui ont été établies pour avoir eu lieu dans les années 2004 - 2005 et 2008-2009. L'année la plus humide était 2003 et correspondait à une augmentation de l'indice de végétation NDVI. Une forte corrélation positive entre les précipitations et la végétation a été établie (r = 0,99).

Les précipitations ont influencé la biomasse végétale dans le corridor du bétail, car il existe une corrélation positive entre les précipitations et la production de la biomasse végétale. Deuxièmement, la végétation est susceptible d'être concentrée dans les zones qui auront de fortes précipitations en 2070-2100, comme Luwero et les districts du Sud de celui-ci du corridor du bétail par rapport à ceux dans le nord du corridor du bétail de l'Ouganda.

Mots Clés: NDVI, précipitation, pluie, SPI

INTRODUCTION

Increasingly, the pastoral production systems in Sub-Saharan Africa face - more frequent and severe droughts in recent years according to the African Union (African Union Policy Framework for Pastoralism, 2010). In the cattle corridor of Uganda, droughts have affected significantly the production potential of pastoralism, the activity being largely rainfall dependent (Amaha, 2003). The corridor occupies a significant proportion of approximately (44% of Uganda's total land area (GoU, 2001). It stretches from the south through the districts of Ankole and northern parts of Buganda to the north central part of Uganda covering parts of Apac, Lira, and Soroti districts; up to Kotido, Kaabong, Nakapiripirit, and Moroto districts in the northeast. These areas are generally semi-arid and are roamed by nomads particularly the traditional pastoralists, the Bahima in the south-west and the Karamojong in the north-east.

Studies on terrestrial properties have involved the use of Normalised Difference Vegetation Index (NDVI) data to model time based trends in land cover properties to assess seasonal variability in vegetation (Weiss *et al*., 2004). NDVI is the most widely used vegetation index and many studies have demonstrated its ability to describe vegetative phenology. The main advantages of NDVI for monitoring vegetation are: (i) the simplicity of the calculation; (ii) the high degree of correlation of the NDVI with a variety of vegetation parameters and (iii) the extensive area coverage and high temporal frequency of NOAA-AVHRR data (Hess *et al*., 1996).

Vegetative production in arid and semi-arid regions is closely related to the long-term average precipitation (Rutherford, 1980) and inter-annual rainfall variability (Le Houérou *et al*., 1988). The NDVI has been empirically shown to relate strongly to green vegetation cover and biomass using ground-based studies involving spectral radiometers (Boutton and Tieszen, 1983; Tucker *et al*., 1983; Huete and Jackson, 1987; Beck *et al*., 1990). Many studies (Tucker *et al*., 1983; Hielkema *et al*., 1986; Malo and Nicholson, 1990) indicate meaningful direct relationships between NDVI derived from NOAA/AVHRR satellites, rainfall and vegetation cover as well as biomass. The NDVI has been used extensively to qualitatively infer changes in vegetation response to rainfall in seasonally arid regions (Lambin *et al*., 1993). Malo and Nicholson (1990) studied the relationship between NDVI and rainfall in the semi-arid Sahel of Mali and Niger. They concluded that the monthly NDVI could best be explained by a linear correlation with monthly rainfall. Hess *et al*. (1996) and Van Zyl *et al*. (2004) concluded that there is a strong log-linear correlation between NDVI and rainfall. Di *et al*. (1994) developed an analytical model to investigate the response of peak NDVI and total duration of NDVI to Standardized Precipitation Index.

Standardised Precipitation Index (SPI) is a tool developed by McKee *et al*. (1993) based only on rainfall. Its fundamental strength lies in its ability to be calculate for a variety of time scales. The index has the advantages of being easily calculated, having modest data requirements, and being independent of the magnitude of mean rainfall and hence comparable over a range of climate zones (Agnew, 2000). It has been used to also assess drought events (Silva *et al*., 2007; Moreira *et al*. 2006) and was proven to be a useful tool in the estimation of the intensity and duration of drought events (Hayes *et al*., 1999; Otun and Adewumi, 2009).

In light of this background, the study used NDVI and SPI in determining the vegetative biomass dynamics, its relationship with the inter-seasonal rainfall variation, and projecting the likely vegetative biomass under 2071-2100 projected rainfall condition in the cattle corridor of Uganda.

METHODOLOGY

This study was conducted in two districts of Luwero and Nakaseke located in the cattle corridor of Uganda (Fig. 1). The Uganda cattle corridor exhibits most of the characteristics of rangelands; low and erratic rainfall regimes leading to frequent and severe droughts, and fragile soils with weak structures which render them easily eroded. Pastoralism is the main economic activity and rangelands are traditionally mainly used as a common pool resource. Generally, the corridor traverses an ecologically, ethnically and institutionally heterogeneous zone

Out of a total of 37 districts in the cattle corridor of Uganda, 2 districts were selected as case studies. The case study approach was used so as to understand interactions of the phenomena in the real life perspective (Yin, 2003). Luwero (currently Luwero and Nakaseke) and Kirihura pastoral communities were selected as case studies because of their relatively high concentration of cattle as evidenced in the livestock census (UBOS, 2008).

Temporal variation of aboveground net primary production. NDVI were used as proxy of the aboveground net primary vegetative biomass production, using Satellite Pour l'Observation de la Terre (SPOT) images. SPOT vegetation data, are very suitable for mapping spatiotemporal patterns of aboveground biomass variability

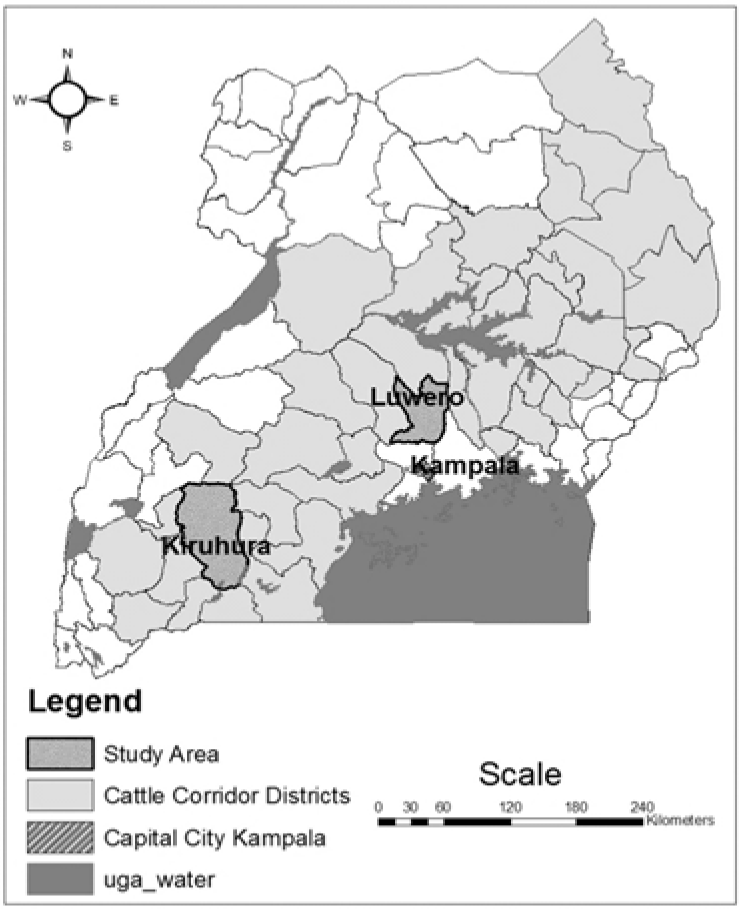

Figure 1. Map of Uganda showing the cattle corridor and the selected study area.

since they are cloud free (Campbell, 2006). Stacked and geo-referenced SPOT images of 1 Km spatial resolution, covering the period March, 2001 to November, 2010 (9 months per year) were obtained from Eumetcast portal. The NDVI was calculated from atmospherically corrected reflectance from the visible red (RED) and near infrared (NIR) channels using the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \ldots\ldots\ldots\ldots \text{Equation 1}$$

Vegetation variation analysis of the 2000 to 2010 NDVI series was done to assess inter-annual changes in NDVI between each successive year under study. A time related analysis was used (Serneels *et al.*, 2001) by subtracting annual NDVI mean values for each successive year. The differences in these image values were used to reveal the scale to which vegetation changed over the years.

SPI determination. The SPI was used to quantify the precipitation deficit on 3 months' time scales. It was computed as the 3 months (Xi) minus the average over 3 months (X) divided by the Standard Deviation of 3 months (ó):

$$SPI= (Xi-X)/\sigma \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

A 10 years (2001-2010) rainfall data set for Namulonge weather station was obtained from the Meteorology Department, Ministry of Water and Environment. The Namulonge weather station data were used as it was the closet to the study area. The SPI values were classified using Table 1.

Projected vegetative biomass (2071-2100). A relationship between the SPI and NDVI values were established using regression techniques in Genestat Discovery 3rd Edition. This relationship was used to estimate the NDVI in 2071-2100, based on Nandozi *et al.* (2012, this volume) rainfall projection, everything remaining similar.

RESULTS

Spatio-temporal patterns of vegetative biomass. The average monthly NDVI of Nakaseke and Luwero revealed a bimodal pattern of the vegetative biomass with seasonal oscillations throughout the year (Fig. 2). High peaks of NDVI were mainly observed in the months of May and November; while sinks were observed in March, July and August. The annual vegetative biomass variation over the past decade is presented in Figure 3. Vegetative biomass fluctuated significantly in the study area with a general decrease. The years 2002 and 2006 corresponded to the years with the lowest vegetative biomass; yet the year 2008 had the highest vegetative biomass overall.

The profiles revealed a trend where vegetative biomass oscillated seasonally to form a bimodal trend of two wet and one dry season within the year (Fig. 2). Trend analysis of biomass in this study revealed the lowest NDVI values in March and July to August. We used this result to define June to August as dry season. High NDVI values were eminent in the months of April to June and October to November, thus they were defined as wet season months.

Vegetative biomass variation. A change trajectory performed on the annual means revealed the highest increase in vegetation in 2008 and decrease in 2009 (Fig. 4). Factors that affect this disparity are likely to be attributed to difference in the amount of rainfall received in the preceding years.

TABLE 1. Classification for SPI values

SPI	Classification
2.00 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to –1.49	Moderately dry
-1.50 to –1.99	Severely dry
-2.00 and less	Extremely dry

Source: Hayes *et al.* (1999); McKee *et al.* (1993)

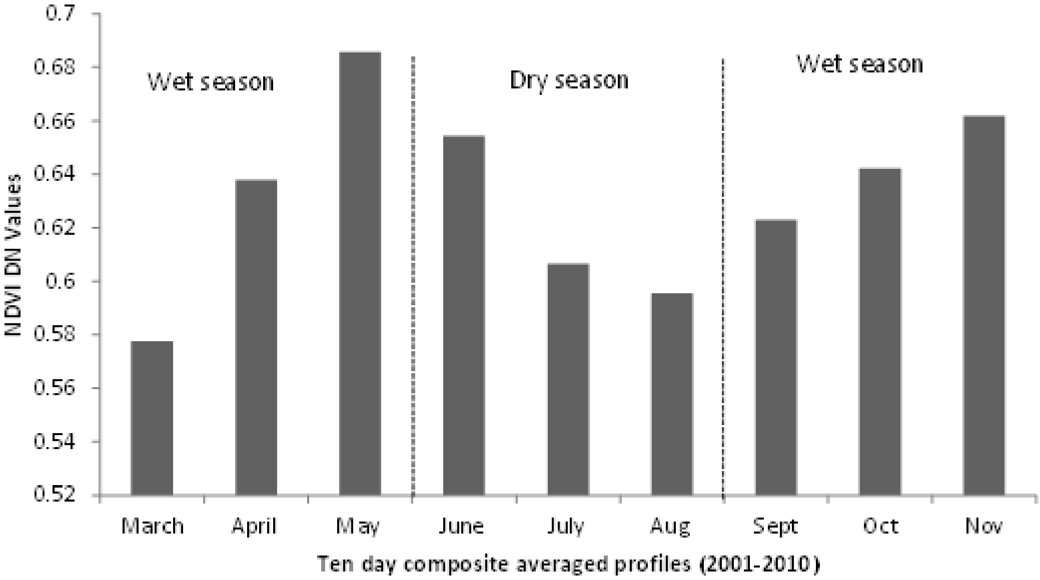

Figure 2. Averaged NDVI (2001-2010) time series for the cattle corridor of Uganda.

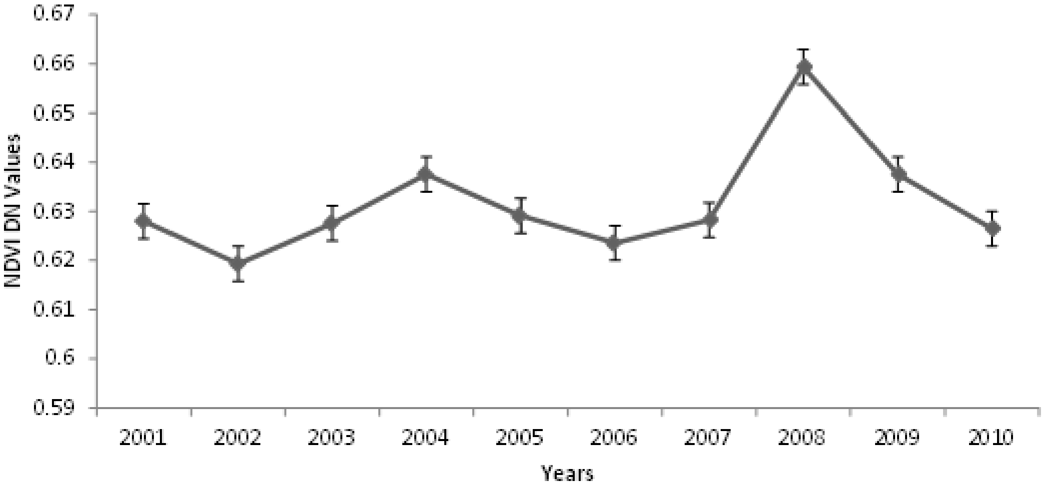

Figure 3. Inter-annual NDVI time series (2001-2010) for the cattle of Uganda.

Change trajectory in this study revealed fluxes in NDVI range, with positive changes corresponding to rainfall conditions, while negative changes correspond to drought conditions.

Standardised Precipitation Index (SPI). Figure 5 shows the SPI trend in the past decade in Luwero and Nakaseke. Two main droughts can be deduced to have occurred in the years of 2004-2005 and 2008-2009. This analysis correlates with what the pastoralists consulted reported. Drought by the pastoralists was said to have occurred in 1998- 2001 and 2003 – 2008. The wettest year was 2003 and does correspond with the increase in NDVI (Figs. 3 and 4).

Analysis of rainfall SPI and NDVI showed a strong positive correlation (r=0.9957) (Fig. 6).

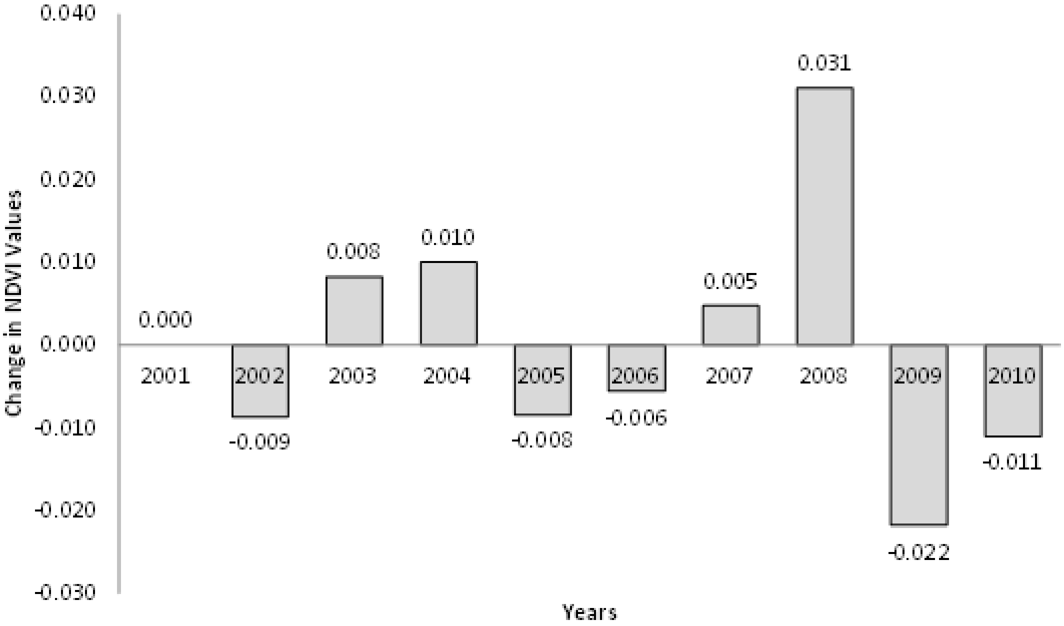

Figure 4. Vegetative biomass variation in inter-annual NDVI series (2001-2010)

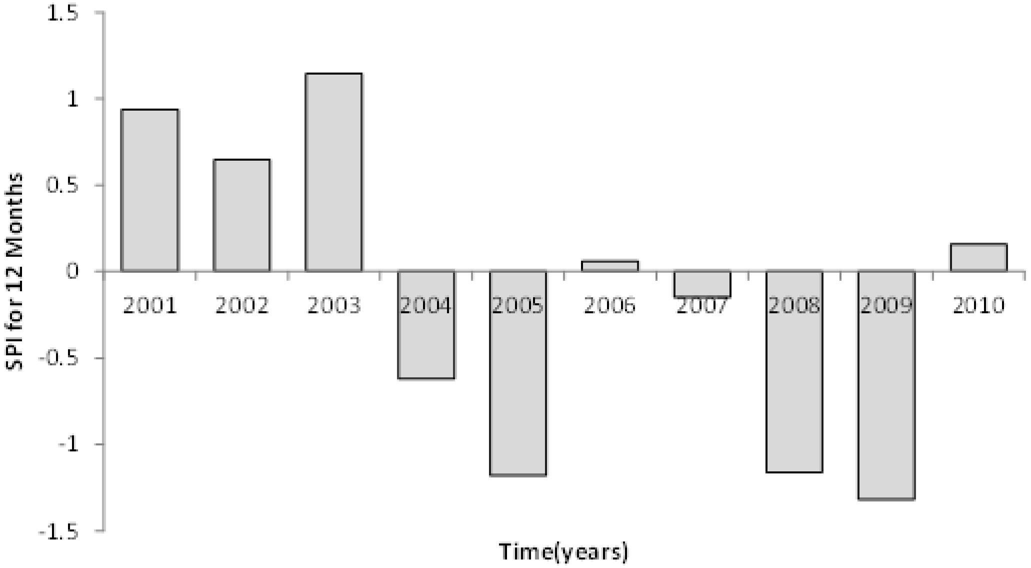

Figure 5. Annual SPI values (2001-2010) for the cattle corridor of Uganda.

Figure 7 shows the projected NDVI that was directly used to infer to vegetation cover. The MAM and SON season will have the highest vegetation cover. The JJA season will have the lowest vegetation cover. Figure 8 shows the projected vegetative biomass spatial distribution of the study area. The projected NDVI will range between 0.13 and 0.56.

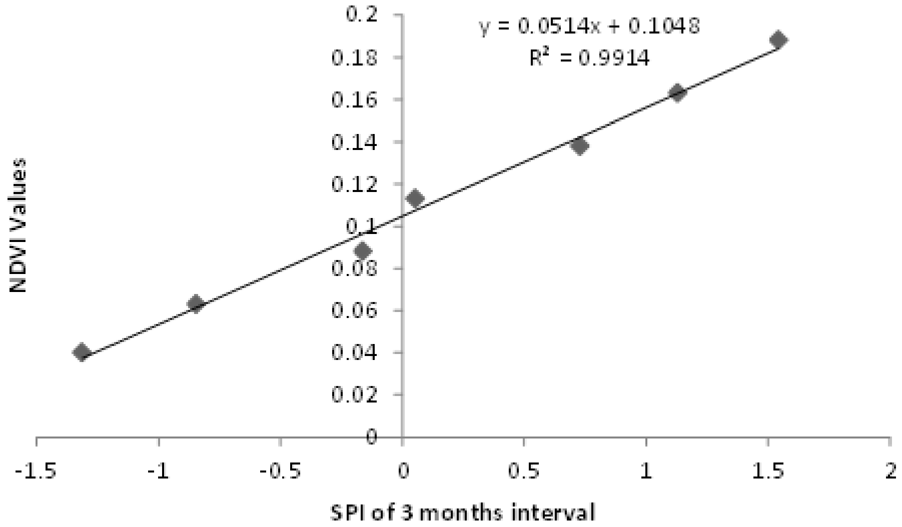

Figure 6. Relationship between NDVI and rainfall for Luwero and Nakaseke districts (2000-2010).

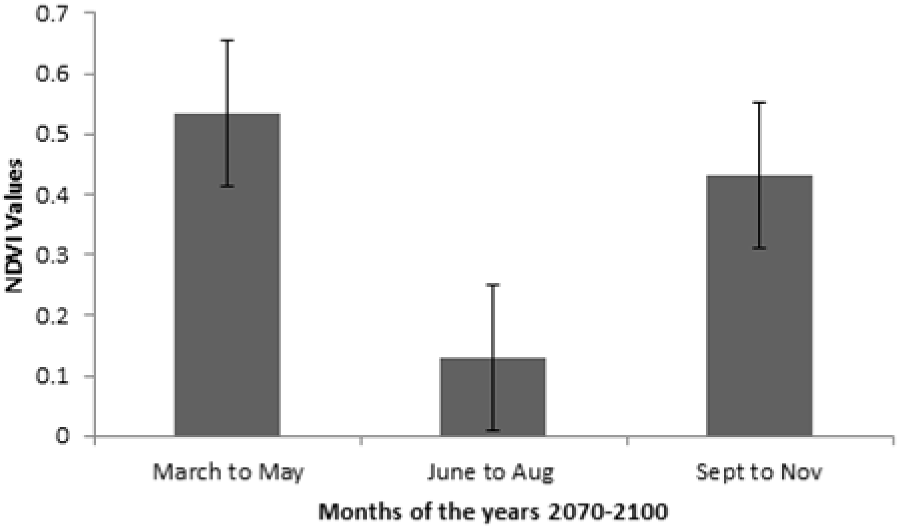

Figure 7. The projected NDVI for the year 2070 to 2100 for the cattle of Uganda.

DISCUSSION

Spatio-temporal patterns of vegetative biomass

These findings are in agreement with other studies in East Africa which used NDVI to reveal a bimodal pattern of wet and dry seasons, in response to the bimodal rainfall in the region (Mulianga, 2009). The seasonal variations (Fig. 2) revealed by this research are analogous to variable responses of different vegetation types to fluxes in rainfall and temperature in different spatial locations (Weiss *et al.*, 2004). Other studies have also found that high biomass corresponds to wet seasons, while low biomass corresponds to dry seasons (Barbosa *et al.*, 2006). This research also realised that the onset of rainfall causes pastures to sprout (Fig. 3.) as plants need rainfall to grow (Mulianga, 2009). NDVI is known to lag behind rainfall by up to three months, as the changes in vegetative cover are not detected by satellite immediately (Eklundh, 1996). The time lag differs between climatic zones; in dry regions

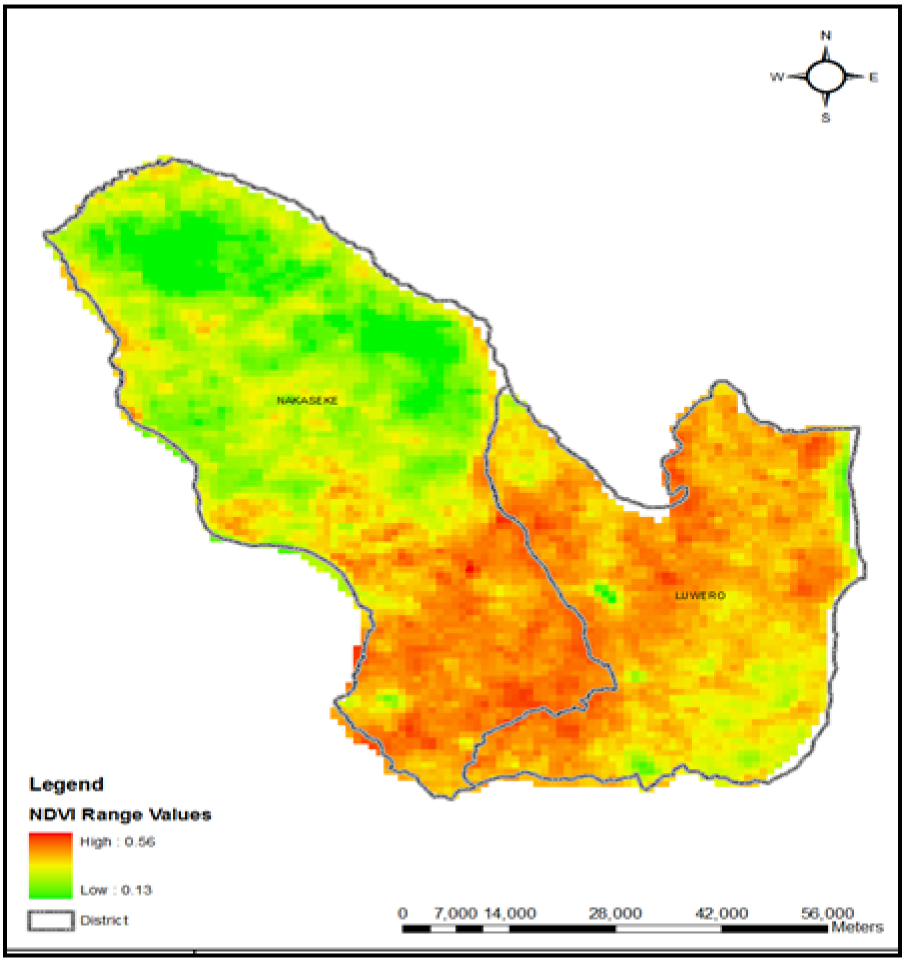

Figure 8. Projected NDVI distribution of Luwero and Nakaseke Districts in the cattle corridor of Uganda.

it is usually shorter than in humid regions. The rapid response to rainfall in dry regions is interpreted to be due to the critical dryness of the vegetation. In dry regions, the dominant vegetation is usually annual grasses/perennials, which respond rapidly to rainfall (Tachiiri, 2003). The satellite observed peak of NDVI (Fig. 2) occurs at the same time as the peak of the delayed response of annuals and perennials to rainfall (Schmidt and Karnieli, 2000). NDVI is also known to be affected by the soil background signal, particularly in arid and semi-arid areas (Huete *et al.*, 1994).

Vegetative biomass variation. Change trajectory in this research revealed fluxes in NDVI range, with positive changes corresponding to rainfall conditions, while negative changes correspond to drought conditions (Fig. 4). Other studies have shown that NDVI fluctuations in 2001 and 2004 correspond to La Nina and drought of the years 2004/2005 (Abbas, 2008). Also that NDVI responds more to drought than higher rainfall (Tachiiri, 2003; Van Zyl *et al*, 2004). It is important to note that NDVI has been used extensively to qualitatively infer changes in vegetation response to rainfall in seasonally arid regions (Lambin *et al.*, 1993). Malo and Nicholson (1990) studied the relationship between NDVI and rainfall in the semi-arid Sahel of Mali and Niger. They concluded that the monthly NDVI could best be explained by a linear correlation with monthly rainfall. The best correlations were achieved when the rainfall of the preceding two months was also included.

Vegetation biomass and Standardized Precipitation Index (SPI). NDVI was used in this research as a climatic indicator, owing the fact that vegetation availability is influenced by rainfall and moisture of the soil (McAllister *et al.*, 2006). It is argued that NDVI is not a direct indicator of biomass, but annually integrated NDVI is used as a surrogate for biomass production (Adriansen and Nielsen, 2005). Analysis of rainfall SPI and NDVI was done and shows a strong positive linear correlation (r=0.9957) (Fig. 5). This correlation implied that rainfall predictions could confidently be used to infer to the likely vegetative biomass over the study area. Many studies (Tucker *et al*., 1985; Hielkema *et al*., 1986; Malo and Nicholson, 1990) have made similar direct relationships between NDVI, rainfall and vegetation cover as well as biomass. The predictions show a like polynomial variation of vegetation within the given year in the future.

Hess *et al.* (1996) and Van Zyl *et al.* (2004) concluded that there is a strong log-linear correlation between NDVI and rainfall. Di *et al.* (1994) developed an analytical model to investigate the response of peak NDVI and total duration of NDVI to a rainfall event. They showed that the peak vegetation response to a precipitation event becomes more delayed toward the later stages of the growing season; which could be interpreted together with phenological data specifically if the vegetation is already at the reproductive phase. The study findings agree with these conclusions as a very strong correlation between rainfall and NDVI was established.

Projections of vegetative biomass: areas with high rainfall are likely to have high vegetation biomass (Fig. 8). Nandozi *et al.* (2012 in this volume) made similar conclusions that the September to November seasons will be the wettest and the findings from this study agree with these observations made. Figure 8 shows that the south area of the study area will have high vegetative biomass and the north will have less. The south areas are mainly in Luwero (south parts of the cattle corridor). The north area in the map is Nakaseke. This represents also other cattle corridor parts that are north of Nakaseke.

CONCLUSION

Precipitation has influenced vegetative biomass in the cattle corridor as there is a positive correlation between precipitation and the vegetative biomass production. Secondly, vegetation is likely to be concentrated in areas that will have high precipitation in 2070-2100. Climate change is expected to impact on vegetative biomass production of the cattle corridor in the future. Therefore, it is recommended that an assessment and projection of likely livestock mobility be conducted in the cattle corridor of Uganda. Context specific recommendations to improve the vegetative biomass in the cattle corridor should be identified and implemented.

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REFERENCES

Abbas, A.M. 2008. Drought in Kenya and National Development. United Nations Development Programme (UNDP), Nairobi, Kenya.

Adriansen, H.K. and Nielsen, T.T. 2005. The geography of pastoral mobility: A spatio-temporal analysis of GPS data from Sahelian Senegal. *Geo Journal* 64: 177-188.

Agnew, C.T. 2000. Using the SPI to identify drought. *Drought Network News* 12(1):6-12.

African Union 2010. Policy framework for pastoralism in Africa: Securing, Protecting and Improving the Lives, Livelihoods and Rights of Pastoralist Communities. Department of Rural Economy and Agriculture, African Union.

Amaha, K. 2003. Potentials, roles and constraints of pastoralism and agr-pastoralism in Ethiopia. Merewa, a quarterly magazine. Ministry of Information. Addis Ababa, Ethiopia.

Barbosa, H.A., Huete, A.R. and Baethgen, W.E. 2006. A 20-year study of NDVI variability over the Northeast Region of Brazil. *Journal of Arid Environments* 67: 288-307.

Beck, L.R., Hutchinson, C.F. and Zaunderer, J. 1990. A comparison of greenness measures in two semi-arid grasslands. *Climatic Change* 17:287-303.

Boutton, T.W. and Tieszen, L.L. 1983. Estimation of plant biomass by spectra reflectance in an East African grassland. *Journal of Range Management* 36:213-216.

Campbell, J.B. 2006. Introduction to Remote Sensing. Taylor & Francis, New York, USA.

Di, L., Rundquist, D. C. and Ham, L. 1994. Modelling relationships between NDVI and precipitation during vegetative growth cycles. *International Journal of Remote Sensing* 15:2121–2136.

Eklundh, L. 1996. AVHRR NDVI for monitoring and mapping of vegetation in East African environments. Meddelande från Lund University Geografiska Institution, Avhandlingar. 126pp.

Government of Uganda,2001. Draft rangeland management policy of Uganda of Uganda.

Hayes, M.J., Svoboda, M.D., White, D.A. and Vanyarkho, O.V. 1999. Monitoring the 1996 drought using the Standardized Precipitation Index. *Bulletin of the American Meteorological Society* 80(3):429-438.

Hess, T., Stephens, W. and Thomas, G. 1996. Modeling NDVI from decadal rainfall data in the North East arid-zone of Nigeria. *Journal of Environment* 48:249-261.

Hielkema, J.U., Prince, S.D. and Astle, W.L. 1986. Rainfall and vegetation monitoring in the Savanna zone of the Democratic Republic of Sudan using NOAA Advanced Very High Resolution Radiometer. *International Journal of Remote Sensing* 7:1499-1513.

Huete, A.R. and Jackson, R.D. 1987. Suitability of spectral indices for evaluating vegetation characteristics on arid rangelands. *Remote Sensing Environment* 23:213-232.

Lambin, E.F., Cashman, P., Moody, A., Parkhurst, B.H., Pax, M.H. and Schaaf, C.B. 1993. Agricultural production monitoring in the Sahel using remote sensing: Present possibilities and research needs. *Journal of Environmental Management* 38:301 - 322.

Le Houérou H.N., Bingham, R.L. and Skerbek, W. 1988. Relationship between the variability of primary production and the variability of annual precipitation in world arid lands. *Journal of Arid Environ* 15:1-18.

Malo, A.R. and Nicholson, S.E. 1990. A study of rainfall and vegetation dynamics in the African Sahel using Normalized Difference Vegetation Index. *Journal of Arid Environment* 19:1-24.

McAllister, R.R.J., Gordon, I.J., Janssen, M.A. and Abel, N. 2006, Pastoralists' responses to variation of rangeland resources in time and space. *Ecological Applications* 16: 572-583.

McKee, T.B., Doesken, N. J. and Kleist, J. 1993. The relationship of drought frequency and duration to time scales. In: Hallgren, R.E. (Ed.). 8th Conference on Applied Climatology, American Meteorological Society, Anaheim California. pp. 179-186.

Mulianga, B.A. 2009. Modelling pastoral mobility to accommodate pastoral land use in land administration, a case study of the Isiolo Area, Kenya. International Institute for Geo-information Science and Earth Observation, GEM Thesis number: 2007-06

Nandozi, C.S., Majaliwa, J.G.M. , Omondi, P., Komutunga, E., Aribo, L., Isubikalu, P., Tenywa, M.M., Massa-Makuma, H. 2012. Regional climate model performance and prediction of seasonal rainfall and surface temperature of Uganda. *African Crop Science Journal, Issue Supplement s2* 20(2):213 - 225.

Otun, J.A. and Adewumi, J.K. 2009. Drought quantifications in semi-arid regions using precipitation effectiveness variables. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009http://mssanz.org.au/modsim09

Rutherford, M. C. 1980. Annual plant production-precipitation relations in arid and semi-arid regions. *South African Journal of Science* 76:53-56.

Schmidt, H. and Karnieli, A. 2000. Remote sensing of the seasonal variability of vegetation in a semi-arid environment. *Journal of Arid Environment* 45:43-59.

Serneels, S., Said, M.Y. and Lambin, E.F. 2001, Land cover changes around a major east African wildlife reserve: the Mara Ecosystem (Kenya). *International Journal of Remote Sensing* 22: 3397-3420.

Tachiiri, K. 2003. Time lag between seasonal change in precipitation, NDVI and cereal prices in Burkina Faso. Geoscience and Remote Sensing Symposium, 2003. In: IGARSS 03:1876-1878.

Tucker, C.J., Vanpraet, C.L., Boerwinkel, E. and Gaston, A. 1983. Satellite remote sensing of total dry matter production in the Senegalese Sahel. *Remote Sensing and Environment* 13:461-474.

Uganda Bureau of Statistics (UBOS), Ministry of Finance, Planning and Economic Development (MFPED), 2008. Employment and Earnings Survey 2008. Government of Uganda, UGA-UBOS-EES-2008-v1.0

Van Zyl, D., Malherbe, J. and Petja, B.M. 2004. Using satellite imagery and rainfall data to track climate variability in South Africa. In: *International Geoscience and Remote Sensing Symposium (IGARSS*) 4:1-4.

Weiss, J.L., Gutzler, D.S., Coonrod, J.E.A. and Dahm, C.N. 2004. Long-term vegetation monitoring with NDVI in a diverse semi-arid setting, central New Mexico, USA. *Journal of Arid Environments* 58: 249-272.

Yin, R.K. 2003. Case Study Research: Design and Methods. 3rd Edition. Thousand Oaks, CA: Sage Publications.